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Flat Roof Thin-Film PV Compared to Tilted Thin Film and Crystalline PV

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ABSTRACT

A 36 kW (DC-rated) building integrated photovoltaic system on a light industrial building has been installed with electric power meters and temperature probes to test and compare performance of three different types of solar panels. The first is a unique solar design which consists of two 2,560 watt arrays of unframed thin-film panels placed directly on a flat insulated spray-applied polyurethane foam ("SPF") roof -- ElectroRoof™. These two arrays will be subjected to different conditions and compared to a third 2,552 watt framed thin-film array mounted with an adjustable tilt angle, and a fourth 2,500 watt crystalline array also mounted with an adjustable tilt angle. These three types of PV technology have been compared in both tilted and horizontal positions under variable maintenance regimes.

1. CONTEXT

To satisfy only a fraction of the emerging gap between energy demand and falling oil and gas production (www.oilcrisis.com), society will demand enormous growth rates from renewable energy industries. Timely expansion of wind power, photovoltaics, solar thermal, biomass fuels and small-scale hydroelectric power will depend upon accelerated growth rates approaching 50% per year -- for decades (www.ecotopia.com/apollo2). The alternatives are not pleasant to contemplate: wars over oil, massive conversion of coal to liquid fuels at the cost of catastrophic global warming, protests against inherently uneconomical, energetically inefficient and dangerous nuclear power, etc.

2. CAN PV RISE TO THE CHALLENGE?

One hinderance to PV achieving rapid growth is the lingering high cost and awkwardness of large-scale installation. To get beyond this limitation, the ElectroRoof™ thin-film flat roof PV system was designed to minimize field installation:

- Roofing or re-roofing with Spray PolyUrethane Foam ("SPF") eliminates the overriding concern of roof leaks which often weigh against rack-mounted PV.
- Weight of solar panels can thwart the feasibility of an installation, especially in the western or southern states where minimal roofs not requiring design strength for snow loads are common practice. Thin film PV is lighter weight than crystalline PV, and SPF Roofing is lighter weight than other roofing systems. Removing gravel from an old roof and applying SPF roofing followed by a thin-film PV laminate can actually reduce overall roof weight.
- Cost of re-roofing with SPF effectively for the life of the building works out to less than 10% of the PV installation.
- This system also eliminates the cost and embodied energy of support racks.

Another hindrance is the inferior energy payback of crystalline solar cells. The process of producing ingots of silicon is very energy intensive. Sawing ingots into solar cells requires even more energy and renders half of the energy embodied in the ingot into sawdust. If thin film photovoltaics (which contain far less embodied energy per watt of capacity) can perform well in building integrated applications, it may be possible to reduce both the cost and the embodied energy of installation, resulting in substantially improved energy payback to meet the challenge of rapid growth in the industry.

3. OBJECTIVES

The objectives of this experiment were:

- To determine the relative energy and economic performance of thin-film solar arrays placed directly on flat, insulated roofs in comparison to tilted arrays, both thin-film and crystalline, including seasonal losses and gains due to slope ("cosine" gains/losses, light reflection and shading), heat and dust;
- To compare "real-estate" efficiency (annual kilowatt-hours per unit of roof area) for horizontal thin-film arrays vs. tilted thin-film or crystalline arrays;
- To validate certified ratings and manufacturers' claims of power output in real-life conditions;
- To evaluate the relative economic performance of the various solar systems taking into account overall aperture efficiency and cost of installation;
- To evaluate performance of these three configurations with respect to panel temperature during high peak summer conditions;
- To identify other performance limitations, such as power electronics reaching out-of-limit conditions.

Results are being displayed on the web (www.ElectroRoof.com) to provide visibility for all the stakeholders involved in the project.

4. DESCRIPTION OF TEST

The test platform consists of four arrays using three types of photovoltaic panels (See Table 1): horizontal thin-film amorphous laminates (Fig 6), tilted framed thin-film amorphous panels, and tilted crystalline panels (Fig. 7).

Each solar array is tied into a single SMA "Sunny Boy" inverter, and the wiring from the arrays is combined into the building's 208 volt three-phase electrical buss, along with 11 additional crystalline arrays not used in the experiment.

The test equipment itself consists of a SolarQuest® DataLogger with pulse-type kwh sensors and temperature probes on each of the four test arrays plus a solarimeter measuring horizontal solar insolation.

Testing began soon after the winter solstice in December, 2003, so data is reported here for nearly one quarter of the year, to March 21st, spring equinox.

5. ANALYSIS

Observations to date are evident in the graphs which follow below. Corrections for slight differences in the array sizes and ratings were made.

CONCLUSIONS

Data continues to be collected in real-time for this test and is available online for review by anyone interested in either testing new hypotheses or challenging the author's conclusions. For details, see www.electroRoof.com/data.

While the evidence is still being compiled as the test approaches the summer solstice, preliminary indications are that ElectroRoof™ is a feasible and economical solution for large-scale building integrated photovoltaic installations.

Table 1. Test Parameters

Quantity	Manufacturer	Model	Description	STC rating	PTC* rating	STC total	PTC* total
20	United Solar Systems Corp.	PVL-128(DM)	Field Applied 3J a-Si Laminate, Deck-Mounted	127.6	118.4	2552	2,368
22	United Solar Systems Corp.	US-116	Framed Triple-Junction a-Si Module	116.0	109.9	2552	2,418
20	Kyocera America	KC125G	High efficiency Multicrystal PV Module	125.0	111.8	2500	2,236
* PTC stands for "PVUSA Test Conditions: PTC watt rating is based on 1000 Watt/m2 solar irrandiance, 20 degree Celsius ambient temperature, and 1 meter/second wind speed. The PTC watt rating is lower than the "Standard Test Conditions" (STC), a watt-rating used by manufacturers.							

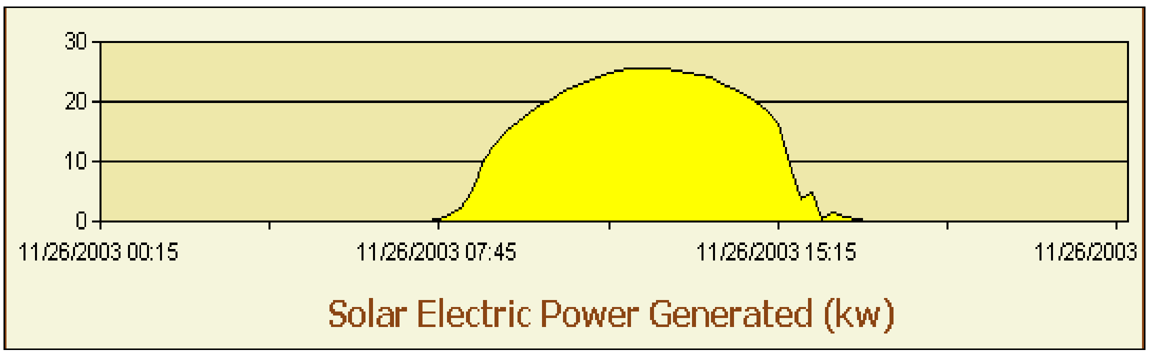

Fig 1. First full day of solar generation upon system startup

Note evidence of inter-panel shading in late afternoon near the winter solstice. Though it is not clear from this aggregate view, this shading occurred on the crystalline PV arrays.

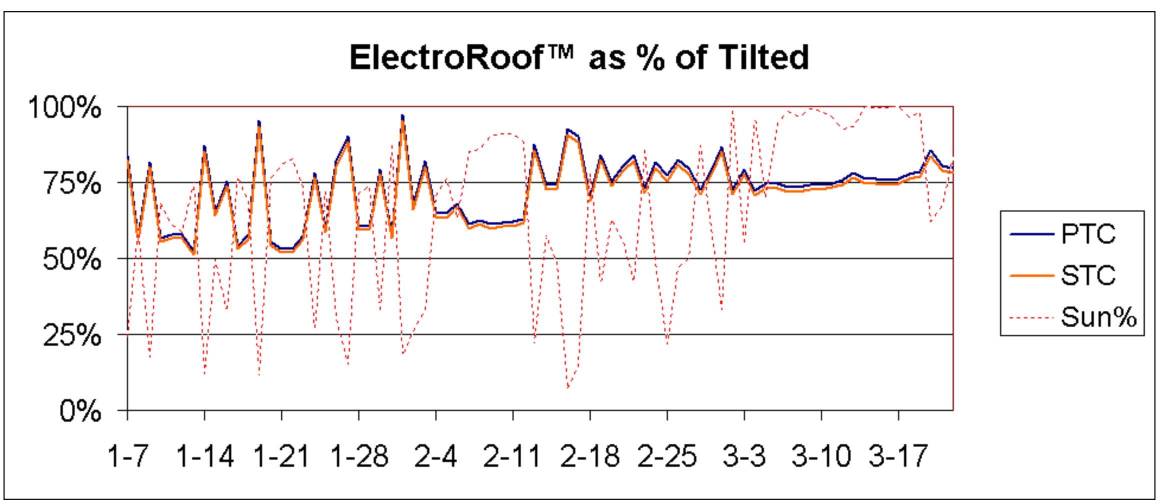

Fig. 2: Horizontal amorphous laminates vs. tilted amorphous panels

Near the winter solstice the horizontal panels produced between 50% and 60% as much as the equivalent tilted panels on sunny days due to cosine losses, but close to 100% on cloudy days under conditions of indirect solar radiation. By March 21, the cosine loss decreased and production for the horizontal arrays was up to about 80% of tilted panels on sunny days.

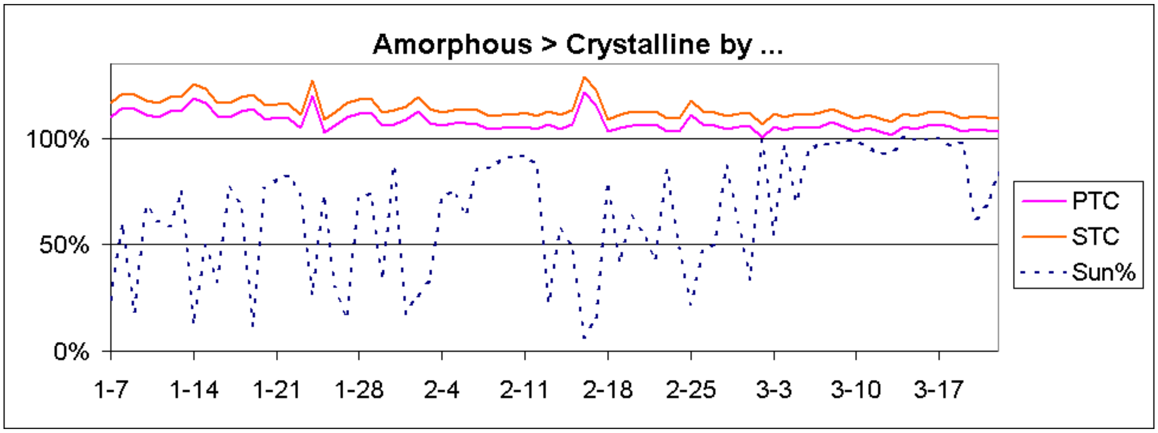

Fig. 3: Amorphous vs. Crystalline panels

Near the winter solstice the amorphous panels produced over 10% more than the crystalline panels (PTC). By March 21, this amount lowered to about 3%-5% more on sunny days. It is possible that this variation is seasonal but it is postulated to be due to the gradual initial degradation of performance that is typical of amorphous photovoltaics, a phenomenon which would be expected to taper off in due course. With the test installation it will be possible to measure this value over time to confirm that the panels' performance eventually stabilizes. How long this will take is yet to be determined. On cloudy days, the amorphous panels produced proportionately more than crystalline by 10%-20%.

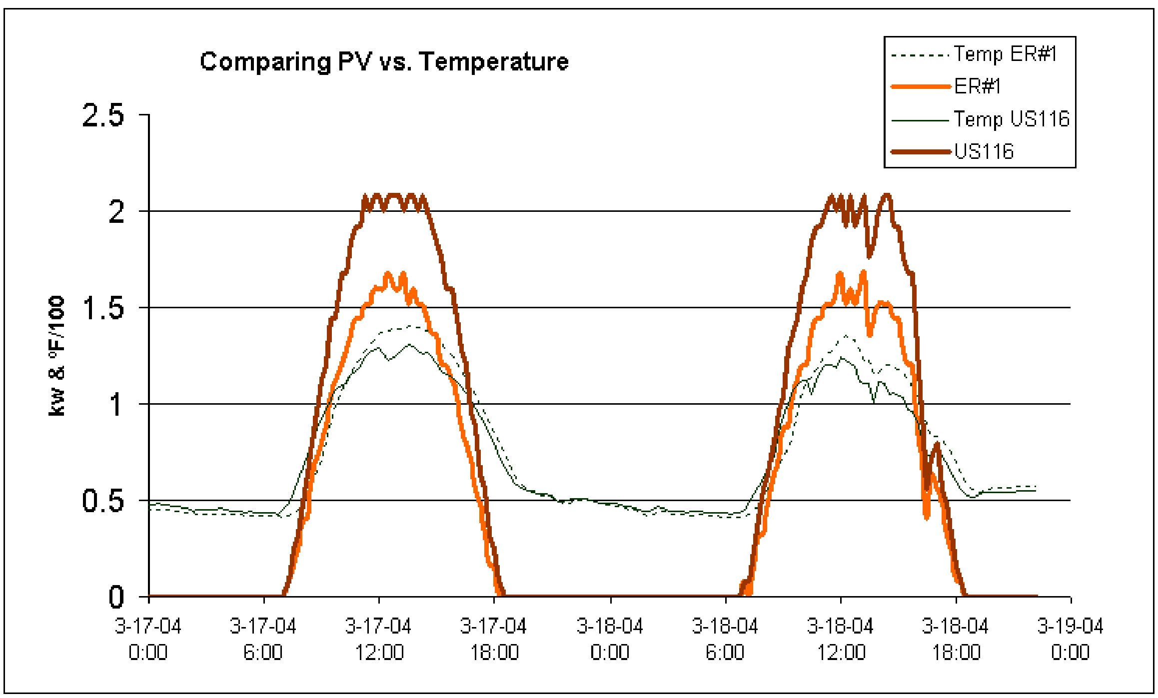

Fig. 4: Comparing PV Output vs. Temperature

The objective is to evaluate performance of the three test configurations with respect to panel temperature especially during high peak summer conditions. In this example, equivalent amorphous panels were compared on record-breaking hot days in March, when ambient temperatures reached 30º C (87º F). The temperature of the horizontal amorphous ElectroRoof™ panels (ER#1) did rise slightly higher than the temperature of the amorphous tilted array but influence of temperature on performance appeared to be minor. More data will be needed to develop conclusive evidence that this is so. As solar production has increased on the path towards the summer solstice, it is possible that the Sunny Boy inverters are cutting out before reaching their maximum rated power output. The inverters are configured at 208 VAC in this case (amorphous) and they are sensitive to open circuit PV voltage levels which do not perform the same as crystalline panels.

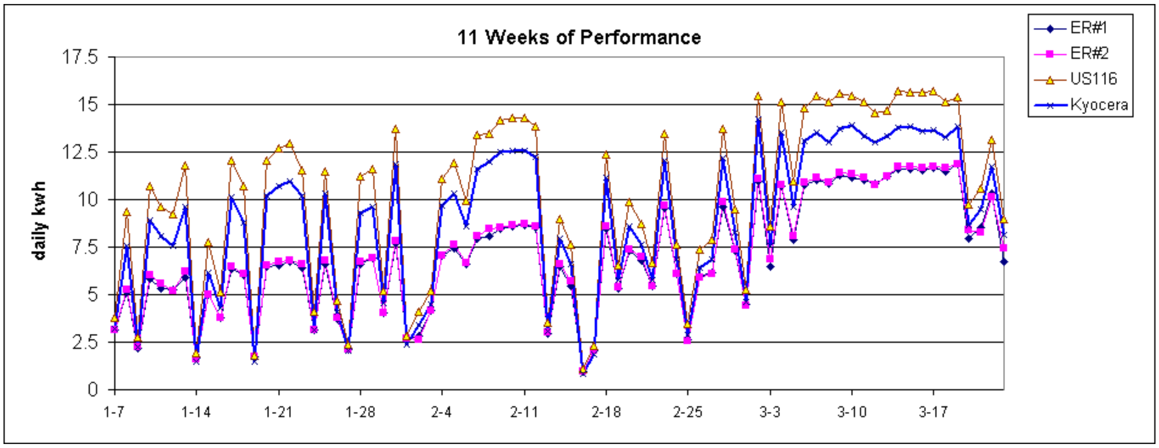

Fig. 5: Overview of individual array performance

The differences between the amorphous and crystalline arrays and the cosine loss for the two horizontal arrays are noticeable in this graph. The substantial convergence of performance under cloudy conditions can also be observed.

Fig. 6. ElectroRoof™ Horizontal Thin Film PV Laminates

Fig. 7. Tilted Thin Film PV panels and Tilted Crystalline PV Panels